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VENTILATION

OF THE

MADISON SQUARE THEATRE.

This description of the ventilating apparatus of the MADISON SQUARE THEATRE is sent you, because you are specially concerned in all that pertains to health as affected by impure air in public buildings. The Theatre is open to you during every week-day, and if you should desire to examine it, please present your professional card.

Elliot, Walter G

VENTILATION

OF THE

MADISON SQUARE THEATRE.

WITH ILLUSTRATIONS.

SCIENTIFIC AMERICAN, *October* 16, 1880.
SANITARY ENGINEER, *October* 15, 1880.

NEW YORK:
MADISON SQUARE THEATRE, 2, 4, AND 6 WEST 24TH ST.

1880.

INTRODUCTION.

The importance of the ventilation of public buildings, especially of those in which large numbers of people assemble, is acknowledged by all persons who frequent them. The subject has received the closest study and attention of the most eminent architects, engineers, and physicians, both in this country and in Europe. Various devices have been invented and tried, but hitherto none have proved fully effective as solving all the problems which the subject presents.

The importance of supplying pure air to auditoriums containing large numbers of people may be fully understood when we realize that it is computed by physiologists that there are 600,000,000 of pulmonary cells or vesicles contained in the lungs of an average-sized man, and that these present to the action of the air inspired the enormous area of fourteen hundred square feet. Then again the air inspired is not all expired by each movement of the chest, but some ten to thirteen per cent remains in the lungs, requiring eight to ten respirations to fully expel it, so that ample time is afforded for the absorption into the blood of any deleterious matter. The cutaneous surface of an ordinary-sized man is estimated at 1550 square inches, and this surface contains, at the lowest estimate, 2,300,000 perspiratory glands, each connecting with the air through the skin by means of a tubular coil, the aggregate length of these tubes being not less than 153,000 inches, or more than two and a half miles. From these tubes, in the form of insensible perspiration, from a pound and a half to two pounds of water are dis-

charged daily, and from the lungs over a pound daily. With these cutaneous and pulmonary exhalations are mingled animal vapors and odors, and these emanating from persons afflicted with pulmonary, scrofulous, and similar diseases, are liable to spread disease among healthy persons who inhale such infected air, unless the precaution is taken of replacing this with pure air.

The management of the Madison Square Theatre, when they determined to make this house the most elegant in this country from an æsthetic or artistic point of view, also determined from the above and similar considerations to make it the most comfortable and healthful theatre in the country from a sanitary point of view. To accomplish this they studied all that has of late years been written on the subject, and counselled with such architects, engineers, and others, whose knowledge and experience in the matter were likely to be of service. The outcome has been the adoption in this theatre of a system of ventilation the results of which are as nearly perfect as can be, making it the best ventilated building either in this country or Europe.

The two following articles fully explain the system of ventilation adopted, the way in which it was carried out, and some of the more important results. They are taken by permission from the *Scientific American* and the *Sanitary Engineer*, and are written by gentlemen having great experience and knowledge of the subject.

From the *Scientific American* of October 16, 1880.

ON THE VENTILATION OF PUBLIC BUILDINGS.

BY JAMES HOGG.

THE art of ventilating public and private buildings is one that has attracted the attention of the public and has been the serious study of engineers and architects for more than fifty years past. Nevertheless, the principles or natural laws which govern it do not as yet appear to be fully understood, or if understood, the proper modes of applying them have not as a general rule been discovered or successfully applied. In support of this allegation we have only to cite the unanimous opinion of our legislators, judges, court officers, lawyers, and others engaged in our courts; of those who attend lectures, concerts, balls, theatres, schools, and churches. All testify that in the buildings erected for such purposes the ventilation is always more or less imperfect, and that great discomfort, ill-health, and even death, is a frequent consequence. The plan, architecture, or decoration of the building may be as perfect as human taste and skill can make it for the purposes for which it is designed, but in one of the most essential features—that of ventilation—it will be woefully deficient, and this again in many cases injures its acoustic qualities and prevents it being properly heated. Within the past twelve months a series of experiments, involving a very great outlay of money, have been going on in a public building in this city, and as they have resulted in obtaining a system of ventilation which is as nearly perfect as it probably can be made, we deem it proper and in

the interests of the public to give a *résumé* of the problems to be solved in this case, and how it was done, as it affords valuable information to those having charge of such buildings.

The management of the most elegant and perfectly arranged theatre in this city, being desirous to have it perfectly ventilated, made a special study of the subject, and called into their counsels persons who had also given the subject great consideration or had large experience therein. Theatres, owing to their requirements and special construction, present greater difficulties in ventilation than any other class of buildings, hence the favorable outcome of the experiments made become of greater importance and value than if they had been made in a building not so imperative in its requirements, nor presenting such difficulties arising from its construction.

The problems to be considered and solved were these :

1st. That the auditorium should be warm in winter and cool in summer.

2d. That the air should not be surcharged with moisture.

3d. That the products of the combustion of the gas lights should not enter into the atmosphere of the auditorium.

4th. That the heat arising from the persons therein, the products of their lungs, and the insensible perspiration of their bodies, should be taken out as speedily as possible.

5th. That the air entering the auditorium should be as much as possible cleansed of dust.

6th. That the system of ventilation adopted should not interfere with the acoustic requirements, but on the contrary, aid them.

7th. That the fresh air should be so introduced as to be equally diffused without producing any sensible draughts.

The first problem, so far as warming the auditorium in winter is concerned, is readily solved by the adoption of any suitable or convenient form of the many appliances in use

for that purpose, causing the air brought into the house to be passed through or over any suitable heating surface. The cooling of the air in summer could only be done by passing the air over some material or substance colder than the air itself, ice or ice-water, or frigorific mixtures, being the cheapest and most easily obtained. A sensation of coolness due to rapid evaporation could be produced by rapid currents of air, although there was no thermometrical difference in the air outside and inside.

The second problem is partly disposed of by the first. Moisture in the atmosphere is always precipitated by cold, as can readily be seen by the condensation of it on the outside of a tumbler containing very cold water, or in the formation of hoar frost on a window on a cold day. As few persons are aware of the amount of watery vapor contained in the atmosphere at different temperatures, we subjoin a table of the amount held therein at the point of saturation. The first column gives the temperature of the air; the second gives the weight in grains of the watery vapor contained in a cubic foot of air when saturated at the temperature indicated :

Temp.	Weight.	Temp.	Weight.	Temp.	Weight.
0°	0·19	35°	2·60	70°	7·94
5°	0·93	40°	3·07	75°	9·24
10°	1·10	45°	3·61	80°	10·73
15°	1·31	50°	4·24	85°	12·44
20°	1·56	55°	4·98	90°	14·39
25°	1·86	60°	5·82	95°	16·60
30°	2·20	65°	6·81	100°	19·13

By the above table it will be seen that saturated air at 100° temperature, when the temperature is reduced to 30°, will have precipitated nearly seventeen grains of watery vapor,

and will therefore be nearly nine times drier at the lower temperature than at the higher, and so in proportion between any other two points of temperature. There are chemical substances which have a great affinity for water, such as sulphuric acid, chloride of calcium, and alumina, or alumine, as it is sometimes called ; the first is clearly inadmissible on account of its deleterious effects on the lungs, the second is liable to the same objections, but not to so great a degree. Alumina being a simple substance, that is, uncombined with any other, it being pure clay, is not at all injurious, and as it has a great affinity for water, taking up fifty per cent of its weight when perfectly dry, it is probably the best substance that can be used for drying the air artificially, but it does not cool it at the same time. The erection of cold chambers, such as are now used in the preservation of articles of food, in which the cold, dry atmosphere in them is produced by some of the various devices and machines for producing artificial ice, was suggested, but the cost of their erection, and that they would only be needed for three or four months in the year, was a sufficient objection to them. The use of ice was therefore decided upon. When, as in winter time, warm and moister air is needed, the injection of steam from the exhaust pipe of the engine would furnish both heat and moisture.

The third problem was partly solved by inclosing the side gaslights in the auditorium in plate-glass boxes, each set having its separate ventilating flue. The great dome light was also inclosed in glass, the under side being of prisms of glass, arranged somewhat on the Fresnel system, so as to throw the light downward. This dome light had its own ventilating flue, opening out on the roof of the house. The ventilation of the gaslight was produced in the natural way, by the rarefaction of the air, produced by the heat from the combustion of the gas. The arrangement was simple and perfectly effective, as none of the products of combustion, such

as carbonic acid gas, sulphureted hydrogen, ammoniacal gas, or other deleterious products, escape into the auditorium. The footlights of the stage, which are a continual source of annoyance in every theatre, could not be arranged in this way, and presented a somewhat difficult problem. The heat generated by the footlights in this theatre is sufficient to run a boiler for a ten-horse power steam engine. The effect of this immense amount of heat, and the resulting deterioration of the air by the products of the combustion of such a large amount of gas, can be easily imagined. Many halls and theatres are heated almost solely by the gas burned seemingly to light them. The problem was solved by inclosing each footlight in an open hood, or little pulpit, so to speak, which connected with an air tube in common, discharging into air ducts communicating with one of the main discharging air flues.

The fourth problem was the most troublesome of all, as so many points had to be taken into consideration. On an average every grown person makes sixteen inspirations of air per minute, taking into the lungs twenty cubic inches at each inspiration, equal to three hundred and twenty cubic inches per minute, or 19,200 cubic inches, or eleven cubic feet, per hour. In passing through the lungs it loses from four to six per cent of its oxygen and gains from three to four per cent of carbonic acid gas. This gas, as is well known, is extremely poisonous to animal life, acting as a powerful narcotic poison. It is half as heavy again as air, and can be poured from one vessel into another like water. Hence it always settles down into the lower part of the auditorium, as water settles under oil, causing the occupants of the parquet to be entirely enveloped in it, and producing headache, stupor, and other symptoms of narcotic poisoning. Owing to its great specific gravity, as compared with air, spontaneous ventilation will scarcely remove it, hence mechanical means must be used to get rid of it. From the

above it will be seen that if the same air could be breathed over again a sufficient number of times it would lose all its oxygen, and at the same time acquire four per cent of this poisonous gas at each inspiration. Besides this change in the air breathed, six grains of watery vapor are given off every minute from the lungs, and eighteen grains from the skin of every full-grown human being. The ordinary temperature of the human body is about 98° ; taking 73° as a pleasant temperature to sit in, we have twenty-five surplus units of heat arising from each person that must be continuously gotten rid of. Spontaneous ventilation was entirely out of the question, for it would not, and did not, remove the carbonic acid gas, sufficiently supply the loss of oxygen, nor reduce the extra thermometrical heat. Mechanical appliances were therefore necessary ; what they were we will shortly explain.

The fifth problem is one which we have not hitherto seen taken into consideration in ventilation. New York City, and, presumably, all large cities, are in dry weather enveloped in a cloud of soot and dust. This city is generally covered with such a cloud at least one hundred feet high. In view of the immense quantity of air that would have to be forced into the theatre in order to thoroughly ventilate it, the amount of dust in it would be a very serious annoyance to the audience. To obviate this a shaft outside of the theatre, six feet square, was built up to a height of fifty feet, and in this hangs an immense bag or sack, similar to a jelly bag. This bag is of nearly the same height, and the same area at the top as the shaft, and is made of cotton cloth, similar in texture to what is known as cheese cloth. As the air is drawn into the theatre by the mechanical means adopted, it has to pass through the meshes of this cloth, and the dust is thereby sifted or filtered out of it. When this bag becomes loaded or choked with dust it is removed, washed, and then replaced in its original position.

The sixth problem was one of no small importance. The experiments made by Mr. Tyndall for the Lighthouse Board in Great Britain showed that the atmosphere was seldom homogeneous in its nature, that it lay in intermixed masses of different density, and that sound passed through or was deflected by these masses according to their density. If, therefore, a column of rarefied air passed up from the floor of the auditorium and out through the dome light, although the air might be homogeneous, and the utterances of the actors on the stage pass readily through it, yet they would be deflected upward, and the rushing in of the air outside of the immediate column of rarefied air, causing counter-currents, would carry their voices with it, and prevent the intonations and inflections of their voices being properly heard by the audience. So, too, those who would be above the stratum of air, not mixed with the carbonic acid gas of greater density, would hear much better than those who were submerged in it. It therefore became necessary so to admit and direct the currents of air that they should flow from the front of the stage to the back of the auditorium and carry the voices of the actors with them.

The seating capacity of the theatre is for an audience of about six hundred and fifty persons, its cubical contents being about 90,000 cubic feet. Careful calculations showed that, to produce the desired ventilation, 1,000,000 cubic feet per hour would have to be introduced, giving to each person about 1500 cubic feet per hour, or twenty-five cubic feet per minute, and a complete change of air in the house every five and a half minutes. These were the theoretical quantities aimed at, but it was not expected that they would be actually reached, owing to the friction and other obstacles incident to the distribution of the air. To pass this million of cubic feet of air per hour through the auditorium necessitated the passage of two hundred and seventy-eight cubic feet per second, at a velocity of two and a half feet

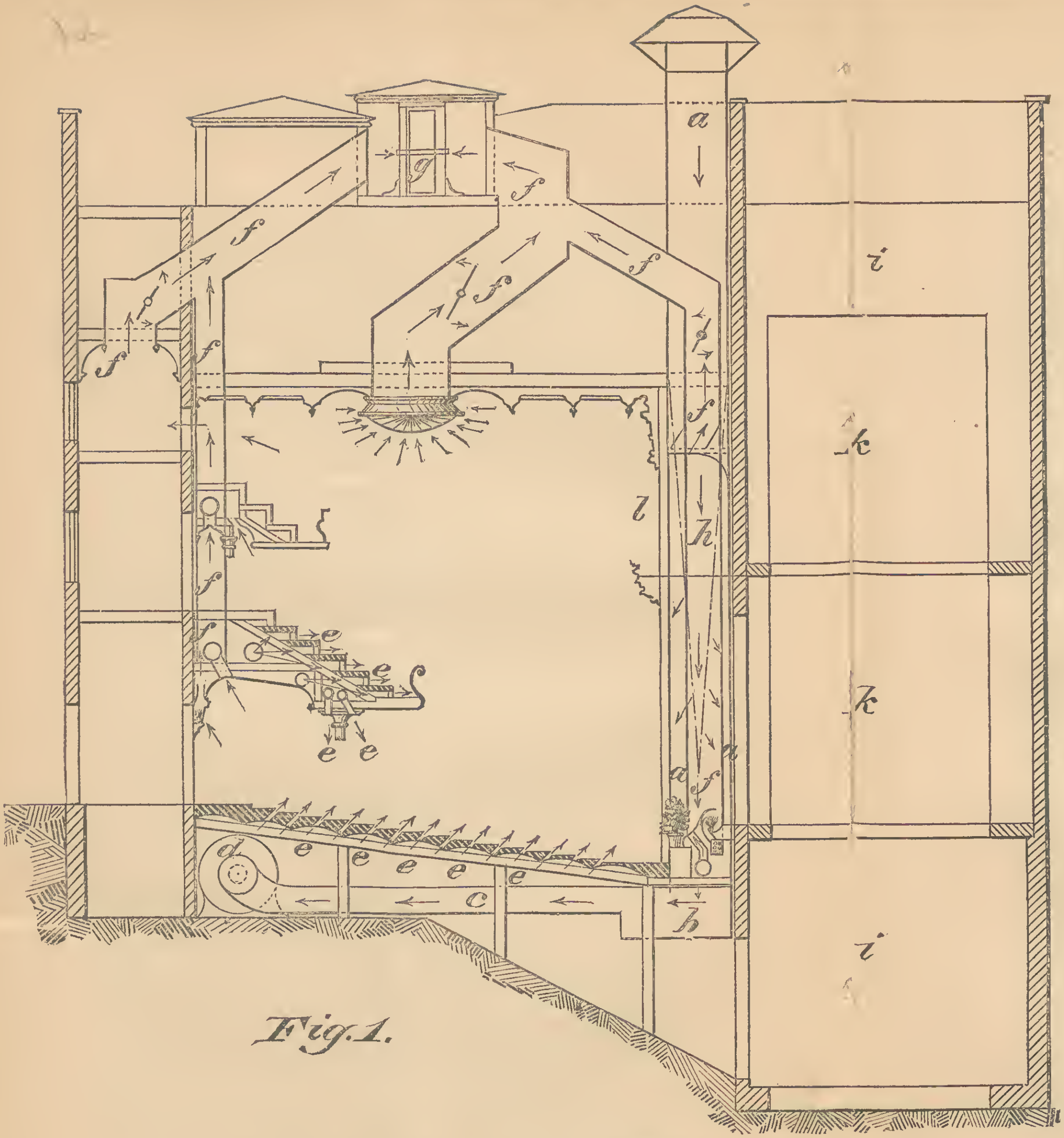


Fig.1.

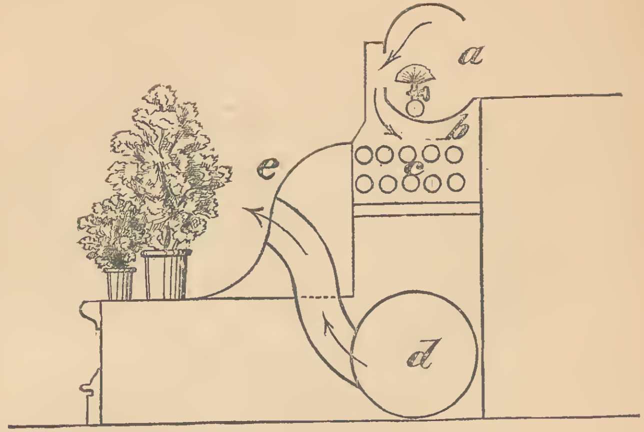


Fig.2.

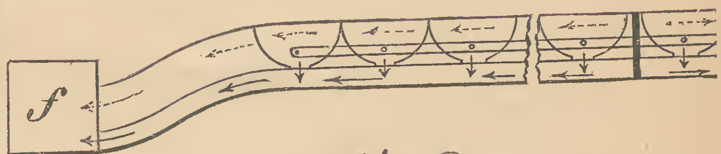


Fig.3.

VENTILATION ARRANGEMENTS OF THE MADISON SQUARE THEATRE, NEW YORK.

EXPLANATION OF THE PLATES.

FIG. 1.—*a, a, a,* Inlet air-shaft. *b,* Ice chamber. *c,* Air-shaft to blowing fan. *d,* Blowing fan, from which the air is distributed by pipes opening under the seats in the auditorium, as indicated by the arrows, *e, e, e. f, f, f,* Outlet or uptake shafts connecting with the exhaust fan, *g. h,* Dust-screener, indicated by the broken diagonal lines. *i,* Stage and scene-room. *k,* Double stage. *l,* Orchestra opening.

FIG. 2.—Enlarged view of the footlight arrangement. *a,* Footlight with hood and opening at the back for the escape of the heated air into the horizontal chamber, *b.* In this chamber the gas-pipes, *c,* for supplying the gas-lights in various parts of the house are laid in order to heat the gas before being consumed. *d,* Air-duct for supplying fresh air in front of the stage. It is distributed through smaller pipes opening through the mask of the footlights; these openings are hidden by rows of living plants.

FIG. 3.—Horizontal plan of footlight arrangement. Each light is screened from its neighbor by a semicircular partition to prevent flickering by lateral currents of air. The horizontal outlet air-shaft is divided in the centre by a partition, so as to send the currents of air right and left to the uptake shafts, one of which is shown at *f,* both here and in Fig. 1. All the horizontal outlet shafts in the house are similarly divided.

The arrows in the figures indicate the direction of the currents of air.

per second, that being the greatest velocity attainable without discomfort, and requires openings of 15,984 square inches, or one hundred and eleven square feet, for its delivery. To accomplish this, nearly a mile of tin and iron pipe have been used to distribute the pure air under every seat in the parquet, and in a continuous circle of perforations from box to box over the parquet, and in the space between the floor of the first balcony and the ceiling underneath, and also across the entire strage front, behind a bank of flowering plants, which, in this theatre, replaces the orchestra, it being located over the stage opening. The air has therefore a sufficient number and area of openings to permit its entrance without discomfort to the audience, but, to aid in this and other objects, the outgoing currents are made to flow toward the back of the house. This was done to attain a twofold purpose—one was to draw the air toward the faces of the audiences for their comfort, and to aid the acoustic qualities of the house by carrying, so to speak, the voices of the actors toward the audience. Openings are therefore made under each of the balconies at the rear of the house, and from these rather than from the ceiling the greater part of the air is taken. Although the air passes through the lower fan at the rate of sixty miles an hour, and through the upper fan at the rate of thirty miles, yet no uncomfortable current is felt in the house.

The mechanical arrangements adopted for bringing fresh air into the theatre consists in connecting a large Sturtevant blower or fan, eight feet in diameter and three feet face, with the upright air shaft before mentioned, by means of a large horizontal air duct. This fan was driven by a small steam engine, capable of working up to two hundred revolutions per minute. All the ventilating machinery is placed in the cellar (underneath the auditorium), which is given up entirely to this purpose, the dressing-rooms, water-closets, etc., being in an adjoining building. The fan de-

livers the air into several smaller air ducts, and these again to nearly four hundred tin pipes, each four inches in diameter. Each of these pipes has a square funnel-shaped opening, covered with wire gauze, discharging through the riser under each chair in the main body of the house. The funnel-shaped mouth and the wire gauze prevent the air from coming out as through a shute, and equalize its delivery. Each person is thus enveloped in a rising body of fresh air. All around the exterior walls under the first balcony are ornamentally masked outlet openings for the exhaustion of the air ; these communicate with air ducts in the walls, and these again with a large vertical shaft connected with an exhaust fan of similar size to that below, placed on the roof of the building. As we before said, the air for the balconies is brought in through the ceiling under the first balcony. These balconies have an arrangement for the outlet of the air similar to that for the lower part of the house. At the lower part of the great vertical inlet shaft are placed sacks holding the ice in layers of its own thickness, and under these is a cemented trough to catch the water from the melting ice. The air passing through the filtrating sack has to pass between the layers of ice and over the surface of the ice cold water before it enters the horizontal air duct communicating with the lower fan. From 1500 to 8000 pounds are consumed every night when the weather requires its use. This is only required on hot, muggy nights, when cold surfaces are covered with dampness, showing great excess of humidity in the air. Except on such occasions no attempt to dry the air is made, as it is unnecessary to do so.

At first only one fan was used, and that below, to force the air into the house. It was found, however, that while it answered an excellent purpose, yet it did not produce perfect ventilation. The ventilation under the second balcony was not as effective as it ought to be, that over the second

balcony was not fully effective, and the trouble with the footlights was only partially remedied. To aid the ventilation, powerful Bunsen burners were put into the upper part of the exhaust shaft, so as to intensely heat and rarefy the air passing through it. This method of producing spontaneous ventilation failed of its purpose, although the fan at one hundred and eighty revolutions per minute was delivering at least 750,000 cubic feet of air per hour, or nearly twenty cubic feet per minute to each person. This allowance is five times as much as engineers consider necessary. To overcome the defective ventilation spoken off, another fan of the same size was placed in a small house on the roof, with the exhaust shaft opening into it, the ventilator of the dome light and another one from over the orchestra, which here is over the proscenium, and from the footlights, also opening into it. This fan is also driven by a small steam engine,and can be run up to the same number of revolutions per minute. The Bunsen burners were of course taken out. When the lower fan is driven at about one hundred and fifty revolutions per minute, and the upper one at one hundred revolutions, a current of air is sensibly felt in every part of the house ; the temperature is but little above that of the external air ; no fluffiness or bad odors are discernible ; the emanations from the footlights are carried off, the acoustics are perfect, and there is no headache or sleepiness produced in the audience. The ventilation is as nearly perfect as it is possible to make it. It should be added that the windows and doors are kept closely shut during the performances. If any one needed to be convinced of the necessity of ventilating large audience-rooms, a visit to the small room containing the exhaust fan would soon convince him. The emanations from the gas lights, the effluvia from the persons in the audience, with a mixture of the perfumery on their handkerchiefs and clothes, is quite nauseating to a person of delicate olfactories.

The difficulties that had to be surmounted, and the experiments made in this case go to show very clearly that spontaneous ventilation is wholly inefficient in ventilating buildings where there are large numbers of persons assembled, and that the forcing of air into a building is almost equally insufficient, and but slightly more efficient, when combined with spontaneous ventilation. It shows clearly that the only true mode of obtaining thorough ventilation is by the exhaust system or pumping the air out, under some circumstances combined with the repletive system of forcing the air in. The following considerations will show why this is so :

Hitherto it has been almost the universal theory of those who have paid any attention to the ventilation of public buildings that fresh air must be forced into them, and all their contrivances for ventilation have been devised under that theory. Unfortunately they have taken hold of the wrong end of the subject, and have to a greater or less degree always failed in attaining the desired results. The real problem is, how to get the vitiated air out of the building. If this is done, nature, through inflexible laws, will see to it that fresh air gets in. We will proceed to show why this is so.

All gases are possessed of two qualities—extreme mobility and great elasticity. As an instance of the first, we would state that ordinary illuminating gas is so mobile that the sudden abstraction of the 1-3000th part of the cubic contents of a gas holder will instantaneously cause a flicker in all the burners conneeted with it ; and also that if the lights are suddenly shut off at any one point it is felt along miles of conducting pipes. For instance, the sudden turning down of the lights in any one of our theatres is almost instantly indicated by the pressure gauges at the gasworks, where a man is kept purposely to watch these fluctuations and to regulate the supply valves in accordance therewith.

This mobility is always in direct proportion to the specific gravity of the gas ; that is to say, the lighter it is the more mobile it is.

The elasticity of gases is proven in the fact that one hundred cubic inches of air under a pressure of fifteen pounds to the inch will immediately expand to two hundred inches when the pressure is reduced one half. Contrariwise, if the pressure is doubled it is reduced to fifty inches, and if the pressure is again doubled it is reduced to twenty-five inches. All gases are equally alike in these respects. If, therefore, we exhaust the air, or any portion of air from a room, the outer air will immediately find its way in, unless the room is hermetically sealed ; if, on the contrary, we endeavor to force air into it, we are met by a constantly increased resistance, inversely proportioned to the amount of air forced in. Hence spontaneous ventilation, unless the air inside the room is much warmer than that outside, cannot be made effectual, and mechanical means must be resorted to. But in crowded assemblies, although the air in the room may be much warmer, and therefore more rarefied than the outer air, yet it is so weighted by the increased amount of carbonic acid gas which it contains that the effects of rarefaction are largely neutralized, and the circulation of the air becomes very weak and languid.

It may be asked why, in the theatre in question, it is deemed necessary to furnish such a large allowance of air to each person in the audience, when four cubic feet per minute to each is considered by engineers sufficient for the purposes of respiration ? The answer is, that rapid evaporation produces coolness, and this is obtained by rapid currents of air. On the hottest night this season we were present at a lecture from a distinguished gentleman in one of the finest halls in the city. It was so stifling hot that many persons could not sit out the lecture, and had to leave. At the theatre everybody present sat out the performance, and

many persons expressed their appreciation of the comfort they enjoyed without understanding the means by which it was produced.

The producing of rapid currents of air in a public building is a great aid in heating it when the season of the year requires artificial heat. Stagnant air, or air in a quiescent state, is one of the best non-conductors of heat known; without being in motion, it is almost impossible to heat it to any extent. As a proof of this we will give an instance which occurred at the Patent Office at Washington several years ago. In that building there was a room with only one window in it, and no means of ventilating it. It was found impossible, with a powerful heating apparatus, to get a higher temperature in it than 40°; somebody suggested cutting a large hole in the floor to allow an exit for the stagnant air. This was done, and in a few minutes the temperature in the room rose to 90°.

The application of the principles we have indicated must be intelligently applied in each separate building to be ventilated, as no two buildings are exactly alike in design. They are no new discoveries, but are as old as the creation. Their proper application in each separate case is the only problem to be solved, and that ought to be readily done by any person of ordinary intelligence. All patented modes of ventilation are but empirical devices; they may succeed in one case and fail in half a dozen others. They should never be adopted except as auxiliaries, if such they can be made to be, to the especial case in hand.

[From the *Sanitary Engineer* of October 15, 1880.]

VENTILATION OF THE MADISON SQUARE THEATRE.

BY WALTER G. ELLIOT, C.E., PH.B.

THROUGH the courtesy extended to the writer by Messrs. Frohman and Barnes, an examination of the system of ventilation in this theatre was recently made, greatly facilitated by the careful and accurate information given by the latter gentleman, who is the engineer in charge.

The system in use is of the most elaborate and expensive character, and no pains or expense seem to have been spared to make it the most comfortable place of amusement in the city.

A visitor entering the cellar would be amazed at the labyrinth of ventilating flues and pipes, converting the theatre into a perfect sieve for the passage of air. This change of air is produced artificially by combination of forcing and aspirating fans, arranged as follows :

From near the rear end of the gable a square wooden cupola rises to a height of about twenty feet above the roof. Each side of this is provided with two sliding shutters operated by ropes from below. These openings face the cardinal points of the compass, and are used in pairs ; thus, if the wind is southwest, the shutters at the south and west are opened while the others remain closed. The shaft into which these open is square, six feet in section, and extends downward behind the scenes to the cellar.

This inlet shaft, as well as many of the larger ducts, is

constructed of smoothed pine boards, sheathed in places with paper, and having few bends.

Suspended in it, point downward, is a conical-shaped cheese-cloth bag, about forty feet deep, through which the incoming air is filtered. A chamber at the bottom of the inlet is provided with a number of shelves inclined at an angle of about 45°, upon which, in summer, ice is placed to chill the air. From this point the main duct, diminished to a diameter of four feet, connects at the axis with a Sturtevant fan, eight feet in diameter, with blades three feet by eighteen inches, and making 150 revolutions per minute. The periphery of this wheel, moving at the rate of about two thirds of a mile per minute, forces the air at a high velocity into the delivery duct, five feet by three feet, in which is placed another mass of ice. Four tons are used every night, two in the delivery and two in the inlet duct.

The delivery duct is of brick, and is branched into six sheet iron pipes, each two feet in diameter. Four of these open into four brick chambers, four feet square. Three steam radiators are placed in each chamber to supply heat in winter.

The floors of the auditorium are divided into four sections of ninety seats each, and every individual seat is supplied from the chambers by 4-inch tin pipes, ninety of which are connected with each chamber.

Two of the 2-feet flues from the main brick delivery duct have not yet been accounted for. Each of them is subdivided into three smaller sheet-iron flues, one set of them passing up the side wall on the right and the other on the left of the house and opening into the auditorium through several four by ten inch orifices just beneath the first balcony ten feet above the floor, and also through a number of 2-inch openings in the lower edge of the balcony, and also across the entire front of the stage.

Through the former openings in summer the cooled air is

poured into the house to reduce the temperature, and to furnish a supply for respiration.

The dome chandelier, together with each wall bracket, is encased in glass, and passes the products of combustion into separate flues connected with the exhaust fan. The proscenium boxes and the elevated orchestra chamber have their separate inlets and outlets, while the galleries are as well supplied as the parquet.

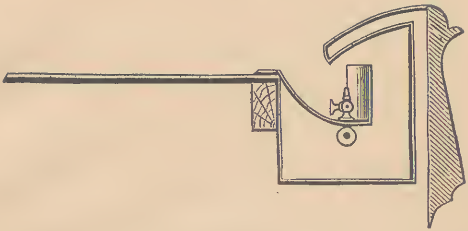
Another Sturtevant blower, 8 feet in diameter, located upon the roof near the middle of the building, is employed to exhaust the foul air.

A wooden flue, four feet by five feet, descends from this at a sharp incline to the floor of the attic, there dividing at right angles into two smaller ducts three feet square. These are again sub-divided in two, twenty-four inches square. Two of them withdraw foul air through six 6-inch pipes in the ceiling under both sides of the first balcony.

The two others pass down to the lobby, opening into two twenty by twenty-four inch registers in the wall and located near the floor on each side of the main entrance.

An additional register, five feet in diameter, is placed in the ceiling at the rear of the upper balcony and connected by means of a large flue with the main exhaust duct.

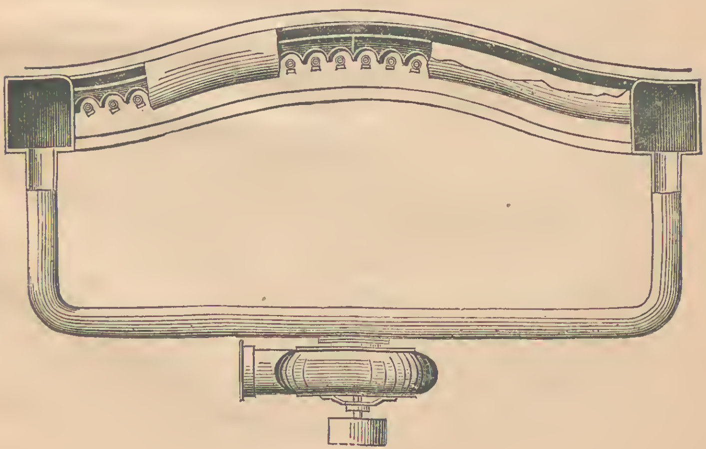
One other feature remains to be mentioned, viz.: the ventilation of the footlights. Behind the row of jets is placed a strip of sheet-metal six inches high, resembling corrugated iron, the corrugations being large enough to form small niches, or "pulpits," as they are called, in each of which a jet is situated. Behind this sheet a hollow space communicates with an 18-inch flue, extending each way from the centre to the side of the stage, and thence through hollow iron columns to the exhaust ducts. A metallic hood projects over the top of the row of lights. The products of combustion are drawn back over the top of the niches and downward into the flues of the exhaust.



The action here seems to be complete and satisfactory.

To ascertain the practical effect of this elaborate system, a visit was paid to the theatre on the evening of July 7th by another observer.

At about 9.30 P.M. the driving fan was making 150 revolutions, and the exhaust 82 revolutions per minute. The temperature of the air in the main delivery duct, just beyond the ice, was 70° F. ; that in the lower part of the theatre 80° F. ; at the outlet of the main exhaust flue 86° F. ; while that of the outside air was 85° F. At the close of the play the temperatures were about the same—that in the lower part of the theatre being 82° F. ; at the outlet of the exhaust flue 88° F.



The current of cool air entering through the wire screens in the risers beneath the seats was very perceptible, but not sufficiently strong to create unpleasant draughts. No foul and overheated air could be detected in the upper gallery, and, in fact, the variation in temperature and purity of the air in different parts of the house was so slight as to be almost unnoticeable. The exhaust registers in the lobby, as well as that in the upper balcony ceiling, showed a strong inward current. Those in the first balcony, however, were not so active. The fresh air inlets about the "horse-shoe" and under the first balcony were doing their duty well.

The fan at present in the basement has recently been replaced by one of sufficient power and capacity to overcome all losses from leakage or friction, and is able to deliver *actually* the required theoretical quantity of 1,000,000 to 1,250,000 cubic feet an hour, or about 1500 cubic feet to each person in the auditorium. The upper fan can withdraw this amount at 100 revolutions, while it could easily run to 200 when speedy change of air might be desired.

In conclusion, I would say that I think much better results could be obtained if the exhaust fan were run at a higher rate of speed than on the evening in question. A considerable amount of energy is wasted by the sharp angles at some of the junctions in the exhaust, and to a less degree in the forcing system.

There has also been some bad calculation of the necessary relations of large to smaller diverging flues. The general effect of the system is exceedingly good, however, and an immense improvement over any of the theatres in the city with which the writer is familiar.

Unfortunately I have been unable to make this description complete by a statement of the velocity of the inlet and outlet flues, the total quantity of air introduced, and by an analysis of the air in the room after the audience had been in for some length of time.